

# Experimental study of two-phase flow structure and pressure drop across a sudden contraction in a horizontal pipe

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## Abstract

*Liquid-gas two-phase flows are widely encountered in industrial applications including systems where phase change occurs, transport in pipes as well in various reactors. These systems often exhibit complex geometry comprising singularities such as expansions, contractions, orifices, bends etc. Geometrical singularities have significant effects, on the two-phase flow behavior as well flow pattern, over manifolds the pipe diameter and subsequently the resulting pressure drop. This important subject has attracted several investigations particularly for applications involving design, safety and economical operations.*

*The present work is devoted to the pressure change as well as the flow pattern resulting from the existence of a sudden contraction. The pressure evolution, of air-water two-phase flow, across the singularity in horizontal circular pipe, was measured with capacitive differential pressure transducers. Measurements were conducted upstream as well as downstream the contraction allowing then to determine the pressure drop due to the singularity. The tubes inside diameters are respectively 40 mm and 30 mm with a contraction ratio of  $\sigma = 0.56$ . The superficial velocities, investigated in this work, ranged for the gas from 0.54 to 5.5 m/s and for the liquid from 0.011 up to 0.24 m/s. Substantial two-phase flow distribution were recorded downstream the sudden change in cross-section. In addition, close to the sudden contraction, a significant pressure drop occurs for liquid single phase flow whereas for two-phase flow, a local pressure minimum was not detectable, the vena contracta phenomenon may not occur at all flow rates especially at low values of the latter.*

**Key words:** two phase flow, sudden contraction, pressure drop, flow pattern.

## 1 Introduction

To ensure the distribution of the fluids in the industrial hydraulic systems, one frequently meets singularities which often cause significant modifications of the characteristics of the flow. Among these singularities, the abrupt contraction is relevant in many applications including chemical and petroleum engineering, energy manufacturing units. The design and control of such systems require reliable procedures for the evaluation of pressure losses as well as the phase redistribution induced by the contraction.

Although single flow through singularities has been largely studied, great uncertainties exist as far as the multiphase - flow is concerned.

**Geiger (1964)** [1] measured pressure drops for steam-water mixtures flowing through sudden contractions with area ratios of 0.398, 0.253 and 0.144. The data were compared with the homogeneous model, momentum equation and mechanical energy equation across the contractions, the homogeneous model gave the best predictions of the data. **McGee (1966)** [2] had also measured the steam-water mixtures flowing through a sudden contraction using the same test rig as **Geiger (1964)** [1], but with different test conditions and sections (0.608 and 0.546), the predictions of homogeneous model compared to the test data were fairly acceptable. The predictions by the momentum and mechanical energy equations were much lower than the test data. However, **Schmidt et Friedel (1997)** [3] developed a new model to calculate the two phase pressure drop across a sudden contraction in a duct area, data obtained with mixtures of air and water, aqueous glycerol, watery calcium nitrate and with the Freon 12. They reported that a local pressure minimum was not detectable in the two-phase tests, thus the axial pressure profile and the shape of streamlines in two-phase flow are still unknown, and there is no evidence whether or not the profile is similar to single phase flow. **Abdelall et al (2005)** [4] investigated air-water pressure drops caused by abrupt flow area expansion and contraction in mini-channels, with inner diameters of 1.6 and 0.84 mm for  $1754 < Re_{lo} < 3924$ . The authors pointed out pressure drops data were lower than those predicted by the homogeneous flow model, a significant velocity slip ratio existed at the vicinity of the flow area change and according to their recommendations the homogeneous flow model is not applicable in mini and micro channels. More data points  $Re_{lo} < 1020$ , using the same facility, were reported by **Chalifi et al (2008)** [5]. More recently **Chen et al (2008)** [6] investigated the pressure change and flow pattern in small rectangular channels ( $2 \times 4.2 \times 6.4 \times 4$  and  $4 \times 6$ , respectively) into a 2mm diameter tube. The total mass flux ( $G$ ) ranges from 100 to 700 kg/m<sup>2</sup>s with gas quality ( $x$ ) being varied from 0.001 to 0.8, they reported that the pressure change increased with the rise of mass flux, and gas quality. A modified homogeneous correlation is proposed including the influences of gas quality, Bond number, Weber number and area contraction ratio in the homogeneous model.

The purpose of this investigation is to examine first the effect of the singularity on the flow pattern upstream and downstream the contraction. Then, in accordance with the literature survey, to provide more experimental data on the contraction recorded effects in the range of small channels.

## 2 Experimental facility and measurement techniques

The experiments were carried out on air-water flow at atmospheric pressure in a horizontal pipe with a sudden area contraction. A schematic diagram of the test flow loop is shown in figure 1. The experimental loop is adapted to generate a gas-liquid two phase flow concurrently. It operates in closed circuit for the liquid phase, open for the gas component. The liquid flow is provided by a centrifugal Noryle pump, the nominal operating point gives a volume flow-rate 10m<sup>3</sup>/h for a delivery height of 9m. The air is provided from a compressor. Both fluids air and water arrive in a cylindrical mixing chamber feeding the pipe made of Plexiglas with the resulting two-phase component. Visualization of the flow regime is achieved at 1m from the upstream and downstream of the contraction using a Canon HG20 camera (1920\*1080 full HD 24 bits/s) with high resolution. Gas flow measurements are performed by two Rota meters VMRP010092 and VMRP010083 type. Liquid flow is measured by a portable ultrasonic flow meter type PT878 portable. The estimated incertitude on liquid and gas flow rates were lower than  $\pm 2\%$  and  $\pm 1\%$  respectively.

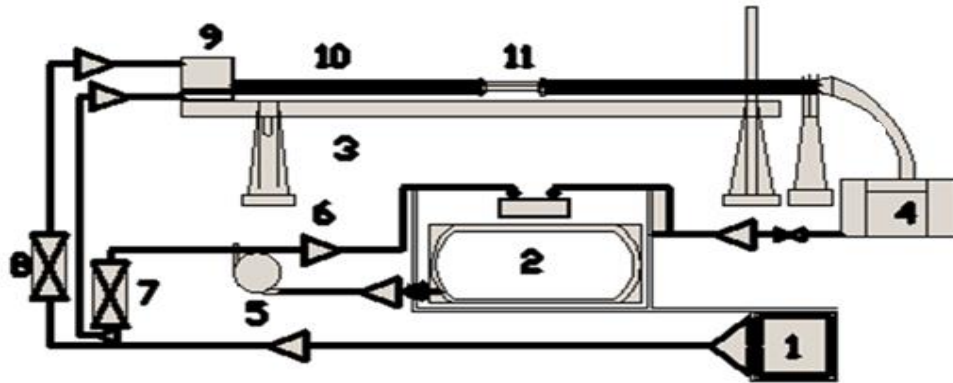


Fig.1. Description of the experimental setup

- |                         |                     |
|-------------------------|---------------------|
| 1: compressor           | 7: Liquid debimeter |
| 2: liquid tank          | 8: Gas debimeter    |
| 3: Frame                | 9: liquid-gas mixer |
| 4: liquid-gas separator | 10: Visual section  |
| 5: centrifugal pump     | 11: Test section    |
| 6: liquid by pass line  |                     |

The test section is characterized by a sudden area contraction with inner diameters of 0.04m upstream the singularity and 0.03m downstream, giving thus an area ratio of 0.567. The horizontality was set beforehand to avoid transition due to the effect of the pipe inclination (Salhi et al.2010 [7]).The air injection system was equipped with air filters to maintain good experimental conditions. Each test was initiated by first verifying that all tubing lines were full of liquid and contained no trapped air bubble. To ensure maximum accuracy the differential pressures between pressure drops was calculated. The pressure drop uncertainty was less than 3.9% which was caused by the two-phase flow fluctuations (slug flow and elongated bubbles). The superficial velocities ranging from  $J_l = 0.011$  up to 0.24m/s, for the liquid phase, and from  $J_g = 0.54$  to 5.5 m/s for the gas were covered in these experiments at room temperature (25°C).

### 3 Results and discussions

#### 3.1. Flow maps upstream and downstream the contraction

The influence of contraction on the flow structure was enlightened with the compiled flow regime maps. For given liquid velocity  $J_l$  a range of air superficial velocities  $J_g$  were swept. The flow regime determination was carried out visually. (Figures 2.a and 2.b), show the predicted flow regime type downstream and upstream the contraction.

The phase distribution downstream the sudden contraction plays important role in pressure determination in this region. The upstream flow patterns in the present study were stratified, wavy, slug and elongated bubble, while the fully developed downstream flow patterns were wavy, slug and elongated bubble.

It should be observed that the stratified flow regime disappeared after the contraction. Furthermore, the intermittent flow (slug/elongated bubbles) prevails before and after the contraction with important modification in regime parameters especially the frequency, length and velocity of the slug; this phenomenon is, for the time being under investigation.

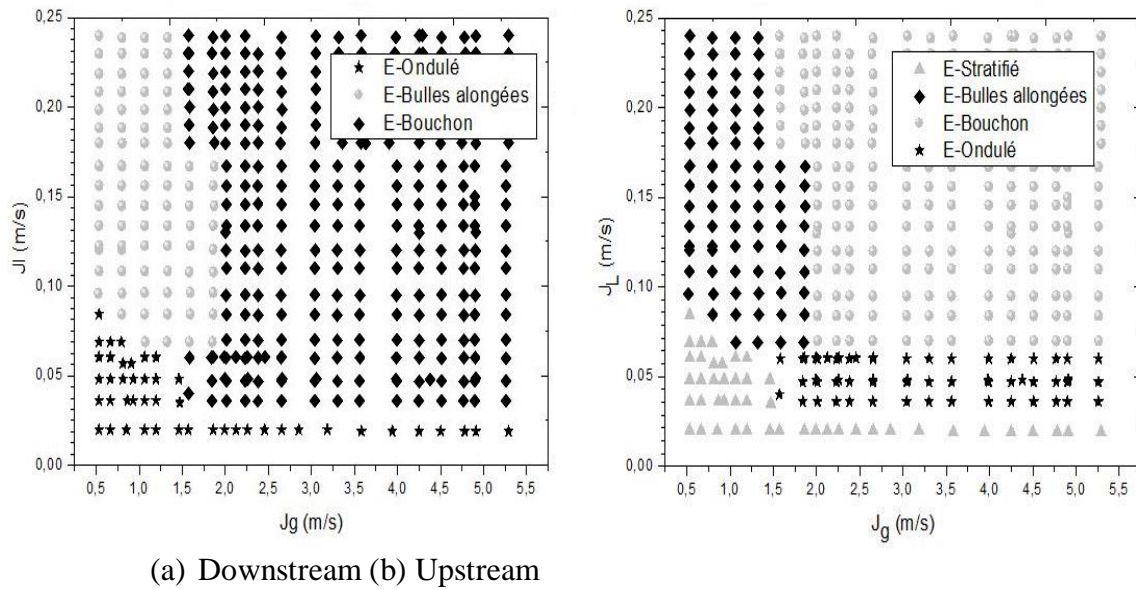


Fig.2. Flow regime maps on the presence of contraction.

### 3.2. Pressure drop

In single phase flow (liquid here) the pressure curves, depicted in figure 3, show an expected minimum in the narrowest flow cross section. The vena contracta phenomenon is felt for about 40 mm behind the transitional cross section and depends only slightly on the flow velocity, the distance relates to about 1.33 times the upstream pipe diameter. The flow becomes stable again at a relatively early position, that is after  $x/d_2 > 13.33$ .

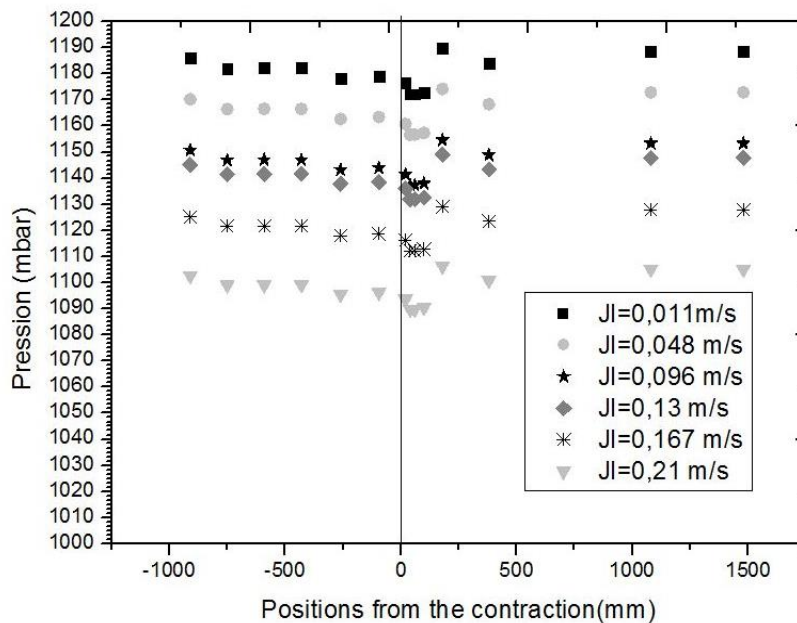


Fig. 3. Variation of single phase pressure.

In figure 4, the measured static pressures in a horizontal air/water flow through a pipe contraction with an area ratio ( $A_2/A_1 = 0.567$ ) are shown as a function of flow axis for various liquid velocities and gas velocities. As expected the pressure steeply decreases at high liquid velocity. Distinctly at low flow rates (liquid and gas) the curves exhibit a wavy course, this is not due to measurement errors, but it

characterizes a slug flow pattern, which is the dominant configuration in our test (see figures 2a and 2b), where the buoyancy force plays a significant role, this phenomenon was characterized by Chen et al (2008) [6] as a change of flow pattern in the inlet pipe or outlet pipe.

Unlike single phase flow, the location of vena contracta, defined as the distance to transitional cross section and the size of the narrowest flow cross section identified from the course of the static pressure along the flow axis (Schmidt et Friedel 1997) [3] was not detectable. The contraction analogy between single phase and two phase flow is not reasonable in this case of flow quality ( $0.0258 < x < 0.13$ ), this result was reported by Morris (1990) [8] for orifice two phase flow and by Schmidt et Friedel (1997) [3] for the flow through a pipe contraction.

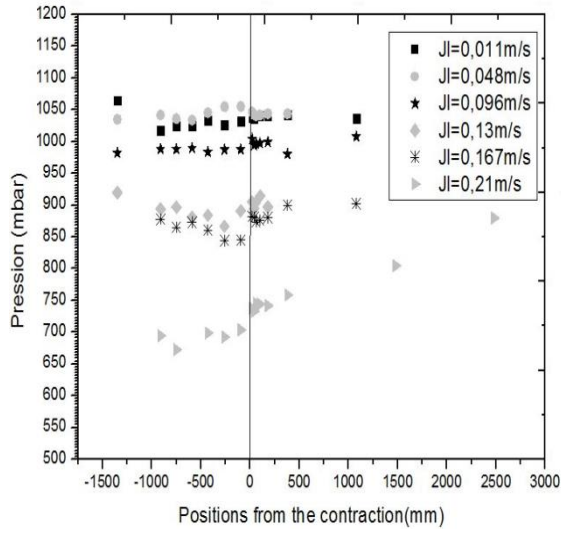
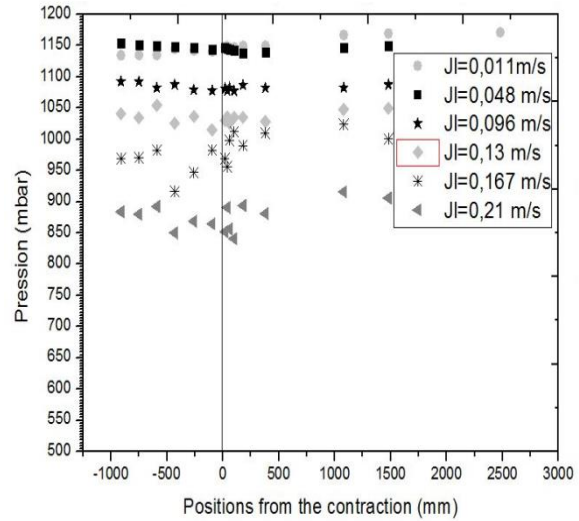
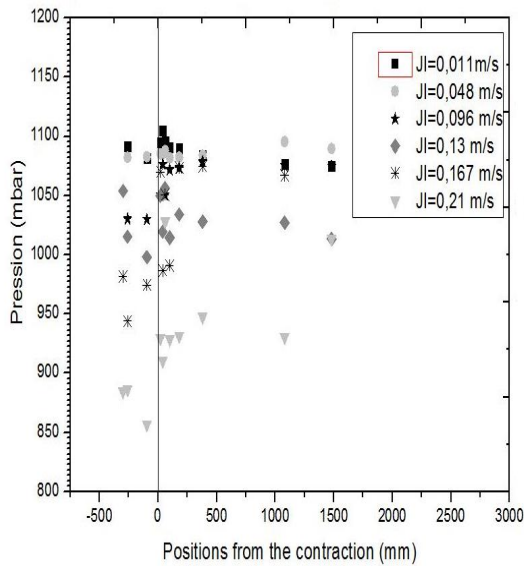
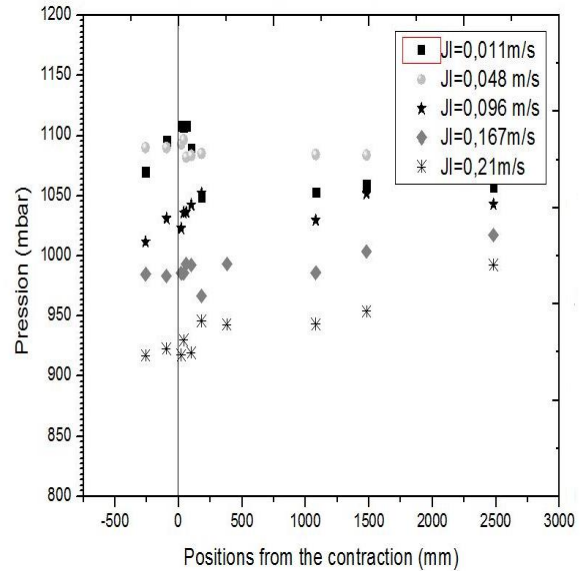
(a)  $J_g = 3.98$  m/s(b)  $J_g = 2.19$  m/s(c)  $J_g = 1.06$  m/s(d)  $J_g = 1.59$  m/s

Fig .4. Variation of static pressure for different liquid velocities

#### 4. Concluding remarks

This study examines the two-phase flow pattern change and pressure change pertaining to the sudden flow area contraction, single phase and two phase flow pressure drops measured in a system consisting of two mini channels, one with  $D=30$  mm and the other with  $D=40$  mm.

The main conclusions of this study are as follows:

-Significant modifications were observed for the flow structure upstream and downstream the contraction.

-For single phase flow (water), a large pressure drop occurs because of the contraction, and the flow becomes stable again at a relatively early position. The vena contracta phenomenon was recorded.

-In case of two-phase flow a local pressure minimum was not detectable and the vena contracta phenomenon may not occur in two phase flow at all especially at low flow rates.

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